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# COMPUTATIONAL THINKING EDUCATION IN THE UK: A TEACHER'S PERSPECTIVE

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## THE UNITED KINGDOM

The United Kingdom of Great Britain and Northern Ireland (UK) is a unitary parliamentary democracy and constitutional monarchy comprising four nations—England, Scotland, Wales, and Northern Ireland—and four education systems. England is the largest country both by land area and population (population 53 million) followed by Scotland (population 5.3 million), Wales (population 3.1 million), and Northern Ireland (population 1.8 million) (UK Office for National Statistics 2011). Scotland, Wales, and Northern Ireland have devolved governments,[1] responsible for a range of policies, with the UK government reserving powers over areas such as macroeconomic policy and defense.

Education is a devolved matter and while each nation has its own school education system, there are commonalities across all four. The majority of children attend state-funded comprehensive schools from age five to eighteen, while Northern Ireland retains state-funded grammar schools for approximately 45 percent of students who pass a selection examination at age eleven (Meredith, 2018). Around 6.5 percent of the total number of school children in the UK attend independent (normally fee-paying) schools (Independent Schools Council 2018).

Although the age ranges vary slightly between the four nations, the primary phase generally lasts from around five to twelve years of age and the secondary phase from about twelve to eighteen years of age.

Students in England, Wales, and Northern Ireland sit for the same public examinations ( General Certificate of Secondary Education (GCSE) at around age sixteen and A-level at around age eighteen), while Scotland has a distinctive system of education and public examinations (taken from about ages sixteen to eighteen) that is separate from the rest of the UK.

## TERMINOLOGY USED IN THIS CHAPTER

### COMPUTATIONAL THINKING

Computational thinking is an approach to solving problems that involves viewing the world through thinking practices derived from computer science (CS). These practices can be grouped into four main areas:

- seeing a problem and its solution at multiple levels of detail (abstraction)
- thinking about problems as a series of steps (algorithms)
- understanding that solving a large problem will involve breaking it down into a set of smaller problems (decomposition)
- identifying similarities and repetition within and across problems (pattern recognition)—and realizing that a solution to a problem may be used or adapted to solve related problems

Underpinning this are some key understandings about computers:

- Computers are deterministic—they do what you tell them to do.
- Computers are precise—they do exactly what you tell them to do.
- Computers can therefore be understood—they are just machines with logical working.

### COMPUTER SCIENCE

Computer science is an academic discipline and school subject that deals with problem-solving through the use of algorithms and data structures to design and create computer programs. While computational thinking can be applied in many school subjects and areas of life, computer science[2] is particularly well placed to deliver it.

### COMPUTING

In an educational context, this is a broad term used to describe all computer-based education in schools including digital literacy, information and communication technology (ICT) (see below), and computer science.

### DIGITAL LITERACY

Digital literacy refers to the ability to use a computer effectively as a tool for learning as well as creating and presenting work across the curriculum. Typically, this involves using the Internet for research and applications packages to present work.

### INFORMATION AND COMMUNICATION TECHNOLOGY

Information and communication technology is a school subject that involves the teaching of core office applications[3]—word processing, spreadsheet, email, and presentation software—largely to secondary school students.

## WHAT IS THE PURPOSE OF EDUCATION?

We are in the midst of a technological and societal revolution that is effecting faster and greater change to society than at any period in history. No aspect of our lives will be left untouched—and at its core is information and computation.

Most would agree that the purpose of education is to produce literate, numerate, and knowledgeable individuals who are ready to take their place in a country's workforce. Today's children will need the knowledge and skills to undertake jobs that will require, or at least benefit from, an understanding of computers and the software that drives them. At a societal level, the education system will provide computing experts to supply an increasingly knowledge-based economy; at an individual level, it will enable young people to gain skilled, high-quality, and well-paid employment.

Education, however, must also be about a deeper, individual benefit, enabling children to develop the knowledge, skills, and abilities they will need to make sense of the world around them. This was as true 250 years ago for Rousseau's *Emile*, educated to navigate his way through the perils of human society and take his place in it (Rousseau 1762), as it is for today's children navigating their way in a society with information and computation at its core.

Children learn about mathematics, science, and history not because they will become scientists, mathematicians, or historians: only very few actually will; rather, they study these subjects—and others—to make sense of the world around them and acquire agency. Someone who therefore does not understand computation and information will not be equipped to cope with the successive waves of technological change that they will live through. In short, they will be unable to participate fully in society. Instead, they will see technology as something mysterious of which they have little understanding and will not be equipped to make informed judgments on technological developments that will affect their lives.

This is why computational thinking must be a foundational discipline, at the core of every modern education system, just like mathematics, science, and humanities. It is this belief that has driven the changes seen in UK computing education in the twenty-first century.

## A BRIEF HISTORY OF COMPUTING IN THE UK

The UK has a long computing history, going back to Charles Babbage in the mid-nineteenth century and Ada Lovelace, often regarded as the world's first computer programmer. The UK can also claim to be the country that invented the computer, in the shape of Colossus—the world's first programmable electronic digital computer—that helped Allied codebreakers to break Nazi ciphers during World War II.

Fast-forward to the early 1980s, however, and the UK had lost its lead, with the US's IBM dominating the first computer revolution, then companies such as Apple and Microsoft leading the second, personal computer, revolution. Enter the UK's public service broadcaster, the BBC, with its mission statement to "inform, educate and entertain." In a tie-up with emerging computer manufacturer Acorn,[4] the BBC sought to introduce the public to computers and show what they were capable of in what would become the BBC Computer Literacy Project. An accompanying national television series *The Computer Programme* began in 1982, showcasing different uses of computers and, importantly, featured projects that introduced the public to programming.

The resulting BBC Microcomputer was, thanks to a UK government drive, adopted by around 80 percent of UK schools (Vasko and Dicheva 1986, 7) and also found success in the home market. With little off-the-shelf application software available, a built-in BASIC programming language interpreter encouraged a generation of school children to learn to program to make it do what they wanted and is credited with helping to kickstart computing education in UK schools (Arthur 2012).

The arrival in schools in the late 1980s of more powerful computers with a range of productivity software available for them largely ended the era of self-made classroom programmers; the emphasis with the new machines was use of office applications rather than programming.[5] Computing education had become about the technology itself rather than the foundational intellectual discipline of computational thinking—creating a generation of tool *users* rather than tool *creators*.

## WHAT WAS HAPPENING IN EACH NATION OF THE UK IN RESPECT OF CT AND CS

By the start of the twenty-first century, school children across the UK received a varying amount of computing education, which could broadly be divided into three areas: digital literacy, ICT, and computer science (The Royal Society 2012, 5).

At this time there was no rigorous primary school curriculum in computing; the level of exposure that children received in the primary classroom was often dependent on whether their teacher was a computer enthusiast. Where computers were used, the focus tended to be on digital literacy and enhancement of learning across the curriculum.

### ENGLAND, WALES, AND NORTHERN IRELAND

In England, Wales, and Northern Ireland, ICT was the mainstream offering in secondary schools, rooted in office applications. Teachers delivering the courses frequently commented that students found this boring and contrasted with the increasingly rich multimedia applications they used at home. While born out of a well-intentioned initiative to create a generation of school leavers equipped with the skills it was perceived they would require in a modern workplace, the subject degenerated into the teaching of outdated skills by teachers, the majority of whom did not hold a relevant qualification (The Royal Society 2012, 72).

CS remained largely a *niche* subject. Many schools did not offer it and among those that did, it was offered from age fourteen and up. It saw relatively low uptake and gradually decreasing numbers (The Royal Society 2012). It was a far cry from being a foundational subject or cornerstone of a modern curriculum.

## SCOTLAND

Things were different in Scotland, where there had been a well-established tradition of CS education in secondary schools since the 1980s. Computing studies[6] was a popular choice for students selecting subjects for public examinations from the age of fourteen, and, despite having around one-tenth of the population of England, Scotland could boast of having broadly similar numbers of students taking CS in the main public examinations (Scottish Qualifications Authority n.d.).

Scottish secondary school teachers are also required to have a university background and teaching qualification in their specialism, so students studying CS benefited from being taught by qualified subject specialists. CS had been seen as an ideal vehicle to deliver digital literacy, however; consequently, courses had become broader, and the number of students choosing the subject had started to decline.

## BEGINNING OF THE GROUNDSWELL

By the early twenty-first century, the situation was therefore ripe for a reboot of the computing curriculum throughout the UK.

**Computational thinking paper by Jeanette Wing** While the phrase *computational thinking* was first used by Seymour Papert in 1980 (Papert 1980, 182), Wing's 2006 paper popularized it and focused minds around what school computing could and should be about. CT also portrayed CS as an intellectual discipline concerned with the type of higher-order thinking identified by Piaget and others (Donaldson 1978) in contrast to what some viewed as the lower-order skills currently being taught. It could be seen that the ability to think computationally would be advantageous to all twenty-first-century citizens and that any country serious about the future of its learners and economy must get behind CT education in its schools.

**Eric Schmidt's comments at the MacTaggart Lecture in 2011** Other publications that followed bemoaned the lack of CT in the UK's schools. It was Eric Schmidt (as chairman of Google), however, who arguably made a bigger impact when he criticized the state of computing education in the UK during his MacTaggart lecture at the 2011 Edinburgh Festival:

> We need to reignite children's passion for science, engineering and maths. In the 1980s the BBC not only broadcast programming for kids about coding, but (in partnership with Acorn) shipped over a million BBC Micro computers into schools and homes. That was a fabulous initiative, but it's long gone.
>
> I was flabbergasted to learn that today computer science isn't even taught as standard in UK schools. Your IT curriculum focuses on teaching how to use software but gives no insight into how it's made. That is just throwing away your great computing heritage.

Schmidt not only laid bare a problem with UK education but dented the pride of a nation that was the land of Babbage and Turing and had created the first electronic computer. As a senior industry figure, his intervention also grabbed media headlines—and the attention of policymakers.

## THE WATERSHED MOMENT

**Shutdown or restart?** At the same time, The Royal Society of London (the UK's national academy of sciences) was investigating computing education in the UK to suggest the best way forward. The publication in 2012 of *Shut Down or Restart? The Way Forward for Computing in UK Schools* was a watershed moment that challenged those in education and government to improve the teaching of computing in schools. Its very title—*Shutdown or Restart?*—suggested that pulling the plug on CT education was a serious prospect.

Published thirty years after the launch of the BBC Microcomputer, it painted a picture of missed opportunities and wrong turns in computing education that had inadvertently led us to the point of near extinction of CS as a school subject, in the quest to create a digitally literate population.

It made several recommendations, including calling for a review of curricula and qualifications, recruitment and training of specialist teachers, provision of continuing professional development (CPD), and better links between school and university courses. Most of all, its principal thrust was to move from teaching tool *use* to tool *creation* through the foundational discipline of CT.

**Computing had changed** These developments were happening against a backdrop of enormous change in computer technology. With the continuing expansion of the World Wide Web and the development of smartphones and tablet computers, computing was becoming increasingly mobile, personal, and more pervasive than ever. Everyone used computers on a daily basis, and industry was desperate for more qualified computing professionals, especially programmers.

**More accessible tools: Blocks-based programming** Furthermore, the tools that educators had at their disposal were changing. The introduction of block-based programming languages, exemplified by MIT's Scratch and App Inventor, made the teaching of programming easier and more accessible than ever before. Anyone who has tried to teach children how to program will know that the first—and for many learners the biggest—hurdle can be working with syntactically demanding, text-based programming languages. Those learners reluctant to persevere, or who have not had a positive experience of education to date, may fall at this first hurdle.

These new environments, on the other hand, allow learners to focus on problem-solving in a way that removes those barriers and engages them. They provide an accessible introduction to programming that allows quick results in a rich, multimedia environment that encourages creativity and exploration.

**Political recognition of the importance of CS** So, the stars were aligned and the gauntlet thrown down. It was up to those in education and government to rise to the challenge and make CT education, particularly through the study of CS, an integral part of a twenty-first-century curriculum.

## INITIATIVES

### ENGLAND

**A new national curriculum** In 2011, the UK government announced a review of England's national curriculum. As part of that review, the government asked two learned societies—the British Computer Society (BCS) and the Royal Academy of Engineering—to draft a new computing curriculum. In 2014, a new national curriculum in computer science was introduced that aims to ensure that all children from ages five through fourteen:

- can understand and apply the fundamental principles and concepts of computer science, including abstraction, logic, algorithms and data representation
- can analyze problems in computational terms and have repeated practical experience of writing computer programs in order to solve such problems
- can evaluate and apply information technology, including new or unfamiliar technologies, analytically to solve problems
- are responsible, competent, confident, and creative users of information and communication technology

In secondary schools, the subject of ICT was to be replaced by computer science. ICT teachers—many of whom had been the school computer enthusiast who had taken on the mantle of teaching the subject—would now be required to deliver a curriculum in which the large majority held neither a relevant degree nor teaching qualifications (The Royal Society 2012, 72).

Computing education would be compulsory and would no longer focus on the technology itself, but on the foundational discipline of CT from the early years to secondary school. Such a bold move, however, presented a huge challenge in terms of support for upskilling many non-specialist teachers in subject knowledge as well as pedagogy.

**Computing at School** Computing at School (CAS)[7] was formed in 2008 as a volunteer-driven grassroots organization that sought to provide support for teachers trying to deliver the new CS curriculum in schools across England and Wales. Adopting a mantra of "There is no 'them,' only us," CAS's declared aim is for "computing with computer science at its heart, to become firmly established in all primary and secondary schools, alongside mathematics and the natural sciences and to support all teachers committed to providing high quality computing education for their students" (Computing at School 2019).

With support from the government and industry, CAS set about building a "network of teaching excellence," whereby "master teachers" would receive training to form and lead local hubs with support from the BCS and computing professionals, including university CS departments. Major IT companies, as well as smaller organizations, provided professional "ambassadors" on a *pro bono* basis.

Computing at School has been a highly successful organization that could be described as an enormous self-help group. Self-sustaining, it remains faithful to its grassroots origins and is now recognized as the official subject association for CS in UK schools.

At the time of writing, CAS has a worldwide membership of over thirty thousand (including the author). Its five hundred master teachers have set up 254 local teacher hubs, and it has delivered more than 4,500 hours of professional learning in the past year. CAS also hosts more than four thousand online resources. Building such a community of good practice will doubtless act as a template for success in other education systems.

**Barefoot—A primary curriculum** In 2014, the BCS set up the Barefoot program with England's Department for Education. Initially funded as a one-year program to help primary teachers in England prepare for the changes in the computing curriculum, Barefoot found early success and funding was taken over by national telecoms company BT in 2015 (which continues to fund it and runs it in partnership with CAS).

Barefoot provides CS teaching and learning resources for primary teachers with no prior expertise; these are designed to be cross-curricular, and most are unplugged[8] to be as accessible as possible. Like CAS, Barefoot adopts a grassroots model, with all content developed by teachers. The project also provides CPD workshops for schools that are delivered by volunteer IT professionals. All of this is free of charge to primary schools across the UK.

Barefoot now has widespread adoption across the UK and a reach beyond its borders. To date, more than seventy thousand primary teachers across the UK have benefited from the project, with 95 percent saying that the professional development workshops improved their confidence and ability in the classroom (Barefoot Computing 2020).

**National Centre for Computing Education** In 2019, the National Centre for Computing Education (NCCE) was set up to work with schools across England to improve the teaching of computing and drive-up participation in post-14 CS courses leading to public examinations.

A consortium made up of STEM Learning,[9] BCS, and the Raspberry Pi Foundation[10] is delivering the work of the NCCE, backed by up to £84 million of government funding.

Chaired by computer scientist Simon Peyton Jones, the NCCE operates virtually through a network of up to forty school-led computing hubs[11] to provide training and resources to primary and secondary schools and an intensive training program for secondary teachers without a post-high-school qualification in computer science. The NCCE works with the University of Cambridge, with a further £1 million investment from Google. Peyton Jones describes it as "the biggest single per capita investment in teacher professional development for computing education anywhere on the planet." Indeed, by late 2020, more than 1,300 teachers had completed the NCCE's Computer Science Accelerator program, ready to teach GCSE Computer Science (National Centre for Computing Education 2020).

## SCOTLAND

**Curriculum for Excellence** "North of the border" in Scotland, things were moving apace. The Scottish government was in the process of a root-and-branch revision of the entire school curriculum and following a lengthy consultation and development period, the new *Curriculum for Excellence* was implemented in 2010.

CS was introduced for all learners from age five to fifteen by adopting three strands:

- understanding the world through computational thinking
- understanding and analyzing computing technology
- designing, building, and testing computing solutions

Like initiatives elsewhere in the UK, Scotland's new curriculum established CT as a foundational discipline from the primary phase (ages c. five to twelve) but also provided significant challenges in terms of CPD for teachers without experience of it.

**National examinations** Following the introduction of the new curriculum, there was a wholesale revision of courses for public examinations. A new course emerged that amalgamated two former courses—Computing and Information Systems—into a single course called Computing Science that largely eschewed application package use in favor of a more formal CS approach through software, database, and web development. The new course runs at various levels of progression from ages fifteen to eighteen.

**The Royal Society of Edinburgh Exemplification Project** Such a radical change required support. With early secondary school (ages twelve to fifteen) in mind, the Royal Society of Edinburgh (RSE), Scotland's national academy of arts and sciences, launched a project to exemplify the teaching of CS both in Scotland and in the rest of the UK. I was recruited to create supporting materials, creating three packs in the first phase of the project (The Royal Society of Edinburgh 2016):

- *Starting from Scratch*: an introduction to CS using MIT's Scratch.
- *Itching for More*: an intermediate CS course using UC Berkeley's BYOB.[12]
- *I ♥ My Smartphone*: consolidating previous work through the medium of mobile app development using MIT App Inventor.

The packs comprise screencasts (tutorial videos) to illustrate program construction for the YouTube generation. A "core + extension" approach allows all learners to achieve success while stretching the more able or experienced, often luring them into making errors and challenging them to debug faulty code. In each lesson, embedded questions encourage discussion and collaboration between students as they seek to tease out misconceptions and reinforce deeper understanding by debugging code samples or examining concepts such as sequencing, scope, and hierarchy.

Mindful that in these earlier years of secondary school CS may be delivered by nonspecialists, the packs also include teacher materials containing pedagogical guidance. Interdisciplinary learning opportunities—a cornerstone of Scotland's new curriculum—are also signposted, encouraging teachers to step out of their comfort zones, while mapping to the curriculum's aims and objectives.

**Computing at School Scotland** Around the same time as the RSE project, Scotland's secondary school CS teachers became more organized, forming Computing at School (CAS) Scotland, linked to its counterpart in England. Working solely on a volunteer basis, CAS Scotland sought to support and provide a voice for secondary school CS teachers. It is true that CAS Scotland is less active than its counterpart in England, possibly because CS was already well established in Scotland with its own online support community CompEdNet[13] and because the pace and scope of radical curriculum reform made it difficult for its membership to commit as much time as many would have liked. Nonetheless, CAS Scotland has provided support for CS teachers, ensuring that their voices are heard during multiagency discussions, and has also organized well-received national conferences for CS teachers.

Following recommendations in the independent *Scottish Technology Ecosystem: Review*,[14] a new body called Scottish Teachers Advancing Computing Science (STACS)[15] has recently been set up to provide further ongoing support to Scottish CS teachers, with funding from the Scottish government (Scottish Government 2022).

**PLAN C** Despite Scotland's CS teachers being qualified in their subject, the new curriculum created a need for CPD for those delivering the courses. As CS had matured as a subject, much of the recent research into pedagogy and how children can learn to think computationally had not reached the classroom.

Consequently, in 2013, PLAN C (Professional Learning and Networking for Computing),[16] a two-year CPD program for secondary CS teachers, was developed in collaboration with the BCS and CAS Scotland, assisted by funding from the Scottish government. The existing subject expertise of Scottish CS teachers allowed the program's creators to focus on pedagogy. Echoing the model adopted by CAS in England, lead teachers were identified who received university training from the project leaders in the latest research as well as use of materials developed by the project staff. These lead teachers returned to their local hubs, delivering training to their colleagues in structured CPD meetings. Time was also set aside at hub meetings for staff to discuss and share classroom experiences—the project's creators considered high-quality professional dialogue to be a vital ingredient of the program—and the collegiate networking that resulted from this was seen as key to the project's sustainability.

By the end of the project, approximately half of Scotland's secondary school CS teachers had received PLAN C training, and the new pedagogy was having a beneficial effect on classroom practice (Cutts, Quintin, Robertson, Donaldson, and O'Donnell 2017, 47–48).

## WALES

In 2008, the National Curriculum for ICT was launched in Wales. The curriculum applied to ages seven to sixteen and required students to develop skills in digital literacy, ICT, and data handling, but there was no requirement to deliver computational thinking.

A new Digital Competence Framework was therefore put in place in 2016, setting out the digital skills to be attained by learners aged between three and sixteen across four strands: citizenship; interacting and collaborating; producing; data and computational thinking.

In 2022, a new national curriculum was launched in Wales that will be introduced to nursery/kindergarten through to year seven (ages three to eleven) and rolled out to years eight to eleven (ages twelve to fifteen) between 2023 and 2026.

The new curriculum contains six "areas of learning and experience" (AoLE), each containing a number of "statements of what matters [for learning]." The science and technology AoLE includes the statement that "computation is the foundation for our digital world" and part of this—programming fundamentals—sees the importance of understanding the fundamentals of computation and is likely to be supported by a range of unplugged activities. Another part—implementation—will see students use programming languages to solve problems after having understood the fundamentals of computation.[17]

Like England and Northern Ireland, public examinations in CS are offered in Wales but not in every school.

## NORTHERN IRELAND

Prior to 2016, the computing curriculum in Northern Ireland focused on the use of computers, much as in England, with relatively little CS (Perry 2015). In late 2016, however, the education minister for Northern Ireland announced the adoption and integration of the Barefoot program into Northern Ireland's curriculum (*Belfast Telegraph* 2016).

This had a major impact, according to Dr. Irene Bell, head of STEM at Stranmillis University College, one of Northern Ireland's initial teacher education institutions[18]. For the first time, CT was explicitly mentioned in the Northern Irish curriculum, although unlike England and Scotland, where CT and CS is a compulsory part of the curriculum, CT comes under the category of a "desirable" strand in the broader ICT curriculum.

Bell therefore undertook a project to map Barefoot resources to Northern Ireland's primary curriculum using terminology familiar to teachers there. Following this, a program of professional development was set up to train the nation's primary teachers in delivery of the Barefoot program. By the end of 2018, almost half of Northern Ireland's primary schools had participated in the training program.

Bell is realistic about the challenges that lie ahead: half of Northern Ireland's teachers still have to be trained, and there remain some hard-pressed primary teachers who struggle to see the importance of delivering computational thinking in an already crowded curriculum. She believes, however, that a focus on teacher training is vital and that with the support of high-quality materials from Barefoot, Northern Ireland is now getting teachers into primary schools who can deliver CT education.

In secondary schools, an ICT curriculum focuses on aspects of digital literacy up to age fourteen. In 2018, the Council for the Curriculum, Examinations & Assessment (CCEA) issued guidance for post-primary schools on delivering CT education, adapted from documentation produced by CAS in England (Berry 2015), although this remains guidance only and is not mandated (Council for the Curriculum 2018). The same public examinations in CS for students aged approximately sixteen and eighteen as those offered in England and Wales are available, but again they are not offered in every school.

## UK-WIDE INITIATIVES

In addition to ongoing work by each of the four nations, there have also been several UK-wide initiatives, many supported by industry.

**Micro:bit** One example is the BBC Micro:bit, a small microcontroller computer developed by the BBC (in partnership with twenty-nine organizations across industry and education) with sensors such as an accelerometer, compass, and Bluetooth as well as a grid of programmable LEDs.

Invoking its public service role, and harking back to the days of the BBC Microcomputer, the BBC sought to "inspire a new generation to get creative with coding, programming and digital technology" with its development.

In 2016, a free Micro:bit was given to every eleven- to twelve-year-old in the UK, with extensive support materials for students and teachers to support CT education and create a standard platform for children and teachers both in the classroom and at home. Research commissioned by the BBC in 2017 on the impact of the initiative suggested that the project was widely regarded by teachers and students as successful (Discovery Research 2017).

**Machine Learning for Kids** The wave of machine learning services that has arrived in our lives prompted IBM UK developer Dale Lane to create *Machine Learning for Kids* in 2017. A free web-based service developed by Lane in his own time, it enables students to create machine learning models—of text, images, numbers, or sounds—that can be imported and used in Scratch, App Inventor, or Python. The site also contains worksheets and projects for teacher and student use and has achieved significant uptake: according to Lane, the system is used to create thousands of projects per month in the UK and hundreds of thousands worldwide.[19]

Not only does this allow students to gain insight into the field and make sense of how facial recognition or recommendations work on Spotify and TikTok but the introduction of machine learning into the classroom also raises questions about the kind of computational thinking that is taught in schools. Arising from this is the recent concept of "CT 2.0"—a more data-driven approach to problem-solving, in contrast to the current rule-driven "CT 1.0," suggesting how CT education must evolve as new paradigms in computing emerge (Tedre, Denning, and Toivonen 2021).

**Charities** Educational charities have also played an important role in the provision of CT education in schools, often in partnership with other organizations and industry. One example is the Raspberry Pi Foundation, which has been closely involved with a number of high-impact initiatives including:

- the Bebras Computing Challenge (in collaboration with the University of Oxford)—the UK arm of the popular computational thinking competition.[20]
- Code Club—a global network of free coding clubs for nine- to thirteen-year-olds run by volunteers and educators.[21]
- *Hello World* (in collaboration with Computing at School)—a free magazine published three times per year for UK-based computing educators to share experiences and learn from each other.[22]

## CHALLENGES THAT LIE AHEAD

In 2017, the Royal Society published *After the Reboot*, an evaluation of the activity that had followed the publication in 2012 of *Shutdown or Restart?*. *After the Reboot* notes first and foremost that there is much to celebrate: many more children are receiving much deeper CT education than ever before (The Royal Society 2017, 5).

This provision, however, is patchy and fragile: only 11 percent of students take the GCSE, the main public examination at age sixteen in CS in England, Wales, and Northern Ireland (The Royal Society 2017, 7), and 54 percent of schools do not even offer the subject at public examinations (The Royal Society 2017, 45). Only one in five CS students is female (The Royal Society 2017, 7).

Continuing professional development is still inadequate with 25 percent of teachers lacking the opportunity to do any professional learning in CS and more than 40 percent who had done less than nine hours (The Royal Society 2017, 73).

**Teacher education** Much has been done to establish CT education in schools, and it is now firmly part of the primary curriculum. This creates challenges, however—both for primary teachers stretched between curricular initiatives and school leaders trying to meet the demands of curricular requirements and school inspectors. Few teachers have studied CS at school, so one of the challenges is building an understanding in teachers of what CT actually is.

Furthermore, while CPD for existing teachers is vital—and much has been done to date—there is also a need for significant CT to be embedded in initial teacher education.

Computing is also a fast-moving field, and the emergence of new paradigms such as machine learning present ongoing challenges in keeping teachers—and the curricula they deliver—up to date.

**CS in secondary schools is facing an existential threat** Following the good work that has been done to establish CT as a foundational discipline in primary education, one might expect an increase in the number of students opting to study CS in secondary schools. Writing in the *Communications of the ACM* in 2015, Alan Bundy and I said of the future of CT and CS in schools that "it could go either way" (Scott and Bundy 2015, 40). Since then, however, the situation for CS as a discrete subject has become more precarious across the UK, and the subject faces a number of challenges that could present an existential threat to it in many secondary schools.

The 2019 Roehampton Annual Computing Education report on the state of CS education in England revealed that the number of students electing to take CS in England's secondary schools was stable at around 12 percent of the student population (Kemp and Berry 2019, 3). The overall number of hours of computing education (including ICT) taught in English secondary school classrooms, however, fell by 36 percent between 2012 and 2017 (Kemp and Berry 2019, 2). The report's authors say that for the majority of students who do not opt to study GCSE computer science (from approximately age fourteen to sixteen), it now looks unlikely that they will receive any computing education in schools thereafter (BBC News 2019).

The picture is similar elsewhere in the UK, with Scotland facing significant difficulty recently. Analysis of statistics published by the Scottish Qualifications Authority (Scotland's national awarding body) reveals a 20 percent decline in uptake of Scotland's equivalent National 5 qualification in computing science (studied from age about fifteen to sixteen) between 2016 and 2019, with numbers in the Higher (Scotland's principal university entrance qualification, taken at around age seventeen to eighteen) down more than 28 percent in the same period (Scottish Qualifications Authority n.d.).

So, despite everything that has been done in recent years, why is CS in such decline, and what can be done to turn things around?

**Availability of teachers** Arguably, the most pressing issue faced by schools is the availability of qualified teachers. It is simply not possible to offer a subject in which you cannot recruit teachers and the number of schools where the subject is offered for public examination remains a concern. In England, 54 percent of schools do not offer CS as a discrete subject (The Royal Society 2017, 45). CAS Scotland reported in 2016 that 17 percent of Scottish secondary schools did not have a specialist CS teacher and the number of CS teachers overall had fallen by 25 percent in a decade (Scotland 2016).[23]

Target and actual recruitment figures to initial teacher education programs in CS indicate recent shortfalls (Robertson 2019), and only 6 percent of CS graduates have embarked on a career in education compared to 11 percent for physics and 12 percent for mathematics (The Royal Society 2017). In Scotland, the number of first-year students on CS initial teacher training courses fell by 80 percent between 2008 and 2017, with some universities dropping their teaching qualification course in CS (The Royal Society 2017).

While the lack of qualified CS teachers is certainly a worldwide problem—even the US saw only seventy-five new CS teachers graduate in 2016 (Code.org 2017)—this must not be used as an excuse for inaction and effectively giving up.

Recent research gives cause for optimism, however; the situation is not insurmountable and needs only a small proportion of CS graduates to transform the situation. For example, it is believed that Scotland would require only fifty to sixty new secondary school CS teachers per year, against a backdrop of Scotland's universities producing four thousand computing graduates per year (Robertson 2019). Furthermore, almost half of recent computing graduates surveyed gave positive responses about the prospect of teaching CS as a career option.

Teaching is not a career that is immediately visible to students being wooed by employers at careers events, however, so there is a role for university CS departments to highlight teaching as a career option to their CS students. This could be as simple as staging talks by recently qualified CS teachers who could evangelize about the rewards and benefits of a career in teaching to undergraduates who may not have considered it previously.

Other initiatives are having an impact. Teach First is a charity and program that recruits graduates into teaching and is now the second largest graduate recruiter in England and Wales with 25 percent of its graduates from STEM subjects (Teach First 2019).

In Scotland, initiatives to get new teachers into the classroom more quickly for STEM subjects include help for former teachers looking to return; bursaries to ease the transition into initial teacher education for those looking to change career (STEM Bursary Scotland 2019); enabling teachers to work in both primary and secondary; and offering more joint degrees in teaching and specialist subjects. A new "Computing in the Classroom" elective is also being offered to final-year CS undergraduates of some universities and for which students receive course credits. This includes a placement in a school CS department, providing insight into the life of a secondary school CS teacher.

**Remuneration** While the potential for high remuneration for CS graduates in industry is often cited as a reason for shortages of CS teachers, research suggests that it is not always the first reason that undergraduates give when explaining why they did not go into teaching—although remuneration remains a significant a consideration for many (Robertson 2019, 21, 25).

A commonly offered suggestion to introduce differential pay—effectively creating a subject-demand-driven job market within teaching—is a thorny issue. Schemes to provide financial incentives for teachers in shortage subjects have been successful in England (Sims and Benhenda 2022), but this is more contentious in Scotland and may struggle to find widespread support.

**Equity of access** For CS to become mainstream in schools, it must appeal to every student, and this is clearly not happening. The ongoing problem of low female uptake also continues to blight the subject.

In 2017, in twenty-five local authorities in England, all the CS entries for public examinations came from boys. At GCSE (England's main public examination, taken at age sixteen) only 20 percent of entries were from female students and only 10 percent at A-level (taken at age eighteen), even though girls are higher achievers than boys at GCSE (Education Business 2018). In Scotland, the number of girls taking the Higher public examination (Scotland's principal university entrance qualification, taken at c.seventeen to eighteen) in CS fell by 28 percent between 2016 and 2019 (and by an alarming 65 percent in CS-related subjects between 2009 and 2019). This is against a backdrop of around half of Scotland's registered CS teachers being female, thereby providing female role models in the classroom.[24]

In the UK, CS tends to be chosen by students from more privileged backgrounds. Roehampton report coauthor Peter Kemp recently said, "It looks likely that hundreds of thousands of students, particularly girls and poorer students, will be disenfranchised from a digital education over the next few years" (BBC News 2019).

Tackling this has been in sharp focus at the National Centre for Computing Education, with each local authority assigned a deprivation index so that efforts can be targeted where they are needed most.

In Scotland, the promotion of social inclusion through reducing the attainment gap (between more and less affluent students) and meeting the needs of all learners have been two major drivers in education policy in recent years, with similar indices for social deprivation used to target support.

**Have we made CS too difficult?** It has been suggested that some students simply find CS difficult and those looking to maximize their grades will understandably opt for the subjects they feel most confident in. By raising the bar and making CS a rigorous academic discipline, have qualification designers made the subject too difficult, forgetting that public examinations are a game of very high stakes? This is a comment I have heard often when speaking to teachers and academics during my research.

Miles Berry, coauthor of the Roehampton report, said in interview that the new GCSE in computer science has earned a reputation for being more difficult than other subjects, discouraging less academically gifted students:

> Even among the academically strong, privileged intake, performance is typically below that of students' other subjects, and thus students, their parents and their head teachers might understandably take the view that this is not an easy way to get top grades. (BBC News 2019).

In Scotland, analysis of SQA statistics (Scottish Qualifications Authority, n.d.) reveals that between 2015 and 2018, CS consistently had one of the lowest A-grade pass rates of any widely offered school subject in major public examinations. If a consensus emerges among students that CS is a difficult option, those seeking to maximize their grades in an increasingly competitive environment may vote with their feet and opt for other subjects. Scotland's new curricular structure has also reduced the number of subjects studied for initial public examinations, creating a squeeze on subjects outside the established core of mathematics, language, and traditional sciences.

It may also be that the current cohort of secondary school students has met CS too late in its school career for foundational knowledge and understanding to have bedded in fully. If so, then the introduction of CT education in primary curricula and fulfilment of CS entitlements may address this issue over the next few years. If, however, the depression of grades and student uptake continues, the relative difficulty of CS qualifications must be addressed.

**Subject pathway** The vast majority of CS courses at UK universities do not require applicants to have studied CS at school. This can convey the impression to school students that there is no need to choose CS courses for their public examinations, even among those who may plan to study it at university.

While this is a necessary position for universities to take when not all students have the opportunity to take public examinations in CS at school, it creates a chicken-and-egg situation—both hampering the subject's uptake in schools and requiring universities to start with a lower bar in their first-year courses. It may also help to explain why CS has the highest dropout rate of any subject in UK universities (Higher Education Statistics Agency 2019), as some students may arrive at university without an appreciation of what a CS degree will involve.

A solution to this would be for universities to recommend a school CS qualification for entry to their CS courses (as several already do). As provision in schools improves, universities could then move toward making the qualification an entry requirement, bringing CS in line with many equivalent subjects. This would benefit both schools and universities, with the potential to produce a larger cohort of better-prepared students.

**The availability of teaching materials** The scarcest resource for any classroom teacher is time. All too often teachers reinvent the wheel, unaware of excellent existing resources that they could use or adapt with relatively little effort.

Teachers now have access to a huge range of materials, but not all are of high quality, and they are scattered across countless sources. There is a need for curation of materials and alignment with curricula. This is now happening with Barefoot materials in particular as they are mapped to primary curricula across the UK, but there remains an ongoing need for work in this area.

## RECOMMENDATIONS

The UK's experiences of introducing computational thinking as a foundational discipline prompt a number of recommendations for those with a similar aim:

### RECRUIT AND TRAIN MORE TEACHERS

Universities, government, and industry must work together to address the current shortage of teachers able to deliver CT as well as specialist CS.

### SUPPORT TEACHERS

Grassroots organizations like CAS and Barefoot work well, providing support and communication through local hubs where teachers can meet, talk, and share materials, as well as active online communities. Teachers must also be offered high-quality CPD and given the time in which to complete it.

### REACH EVERY CHILD

Computational thinking education must be regarded as an entitlement for all learners. It must be embedded into the curriculum from early primary and reach every child from every background. This will, in turn, increase the appeal of CS at the secondary level and help to address the gender imbalance in the subject.

### GET PRE-SUBJECT-CHOICE COURSES RIGHT

Prior to choosing subjects for public examinations, students must be exposed to high-quality CS courses that they regard as enjoyable and relevant. The profile of the subject in secondary schools must also be elevated so that choosing to study CS is as natural as choosing chemistry, history, or a foreign language.

### GET THE HIGH-STAKES EXAMINATIONS RIGHT

Make courses enjoyable, relevant, and challenging—but don't make them too difficult. The number of passes and top grades for CS in public examinations must mirror those in comparable subjects.

### GET THE SUBJECT PATHWAY RIGHT

Universities and schools should coordinate to encourage uptake of CS at school, recommending that prospective CS undergraduates select CS courses for their school public examinations (where they are offered). As provision improves, universities should move toward requiring the subject for entry to CS degrees.

### COORDINATION IS VITAL

Universities, learned societies, and industry are taken seriously by the government, so it's important to get their support and to speak together with one voice.

### EDUCATE KEY INFLUENCERS

Many politicians, parents, and school leaders have little or no experience of CS themselves. It continues to be important to educate them about what computational thinking is and why it must be a foundational discipline.

### THERE'S A ROLE FOR BUSINESS

A significant part of the drive for CT education comes from business, and it is to everyone's benefit that we have a population that can think computationally. Businesses large and small have a role to play here by continuing and expanding their support for CT education at all levels of education.

## CONCLUSION

As the leader of a successful school CS department, I remain optimistic.

Our subject is now on a firm intellectual footing, courses have improved significantly, and, importantly, have stabilized after a period of considerable revision. CT is gaining acceptance as an important foundational discipline; we are seeing students arrive at secondary school who have been better prepared in primary; and even the word "algorithm" is now in common parlance!

The subject of CS must also compete in a crowded curriculum—especially against other sciences—so high-quality courses, teaching, and career advice must convince students of its value. Recruitment of specialist teachers remains an issue, but my department recently hosted its first student teachers in several years who, anecdotally, reported that numbers were up significantly in their courses.

Ultimately, it falls to everyone who cares about CT education—teachers, academics, industry figures, and others—to build on the good work that's been done so far. We must continue to work together and speak with one voice. We must be "squeaky wheels" to get that voice heard and hold the attention of policymakers.

Because there is no "them"—there is only us.

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## NOTES

1. At the time of writing, the Northern Ireland Assembly is in a period of suspension, after it collapsed in January 2017 due to policy disagreements between its power-sharing leadership, resulting in little development in education policy during this time.

2. The terms "computer science" and "computing science" are both used across the UK to refer to the same subject. For the purposes of this chapter, the term "computer science" or the abbreviation "CS" will be used—although in Scotland, the "C" stands for "computing," which arguably conveys a stronger sense of study of the discipline and what the technology can be used for, as opposed to the technology itself.

3. Most commonly Microsoft Office.

4. Acorn went on to rebrand as ARM (initially from "Acorn RISC Machines," then "Advanced RISC Machines"), a company that designs the processor chips that power many current portable devices.

5. Most commonly Microsoft Office.

6. As the subject was called then. New courses emerged called "Computing" and "Information Systems" and, since 2015, the course has been called "Computing Science."

7. https://www.computingatschool.org.uk.

8. A term used to describe computational thinking teaching resources that are done without the use of a computer.

9. The UK's largest provider of STEM education and careers support to schools, colleges, and community groups.

10. A charity founded in 2009 to promote the study of computer science in schools. It also developed the Raspberry Pi single-board computer.

11. Peyton Jones described these hubs as CAS hubs' "mother ships" in discussion with the author, 18 September 2019.

12. A modification of Scratch that has since been updated and renamed *Snap!*

13. https://www.compednet.com.

14. https://www.gov.scot/publications/scottish-technology-ecosystem-review.

15. https://www.stacs.scot/home.

16. http://www.cas.scot/plan-c.

17. Richard Clement (Cardiff Schools Service), in discussion with the author, 21 October 2019.

18. Dr Irene Bell (Head of STEM, Stranmillis University College), in discussion with the author, 4 September 2019.

19. Dale Lane (IBM UK), in discussion with the author.

20. https://www.bebras.uk/.

21. https://codeclub.org/en/.

22. https://helloworld.raspberrypi.org/.

23. Cutts et al. cite approximately 640 practicing computing teachers across 420 secondary schools in Scotland (Cutts, et al. 2017, 34), while Robertson's study suggests that this number had fallen to 595 by 2019 (Robertson 2019, 2).

24. A freedom of information request to the General Teaching Council of Scotland (Scotland's professional registration and standards body for teachers) by the author

in 2017 revealed that there were 1,595 registered Computing teachers in Scotland (794 female and 801 male). It should be noted that not all registered teachers will be actively teaching at any time, however.

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# Computational Thinking Curricula in K–12

## International Implementations

## **Edited by:** Harold Abelson, Siu-Cheung Kong

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